PB85-156792

Automated Closed Loop Control of Ozone Disinfection Using Flow-Paced Off-Gas Measurement

(U.S.) Environmental Protection Agency
Cincinnati, OH

Jan 85

U.S. Department of Commerce
National Technical Information Service
NTIS

PB85-156792

EPA/600/D-85/005
January 1985

AUTOMATED CLOSED LOOP CONTROL OF OZONE DISINFECTION USING FLOW-PACED OFF-GAS MEASUREMENT

by

A. D. Venosa, W. W. Schuk, Hnd H. L. Sparks
Water Engineering Research Laboratory
Cincinnati, OH 45268

WATER ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OH 45268

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA/600/D-85/005		PB85 156792/AS

4. TITLE AND SUBTITLE	5. REPORT DATE
Automated Closed Loop Control of Ozone Disinfection Using Flow-Paced Off-Gas Measurement	January 1985
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
A. D. Venosa, W. W. Schuk, H. L. Sparks	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Wastewater Research Division Water Engineering Research Laboratory 26 W. St. Clair Street Cincinnati, Ohio 45268	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Water Engineering Research Laboratory, Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268	14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Ozone disinfection is an environmentally attractive alternative to chlorine because of the lack of a toxic residual, its excellent virucidal properties, and its reduced potential to form hazardous constituents in the treated effluent. It is, however, energy and capital intensive relative to chlorination, and for this reason it has not been widely accepted yet in the U. S. municipal market. Any method that would reduce the operating cost of ozonation would accelerate its acceptance in that market.

In this paper we report an automated control strategy that, when implemented at treatment plants with a daily average flow greater than 8000 m^3/d, will result in a substantial savings in the electrical cost of production. The method consists of a flow proportional signal and an ozone concentration signal that combine to control the feed gas flow to and the power setting of the ozone generator according to fluctuations in liquid flow and ozone demand. The concentration signal is measured in and transmitted from the off-gas from the ozone contactor. We present an annualized cost comparison of this approach with existing strategies in use today and report a savings of $7,000 to $15,000 per year for a hypothetical treatment plant with a daily average flow of 23,700 m^3/day.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	11
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

AUTOMATED CLOSED LOOP CONTROL OF OZONE DISINFECTION USING FLOW-PACED OFF-GAS MEASUREMENT

A. D. Venosa, W. W. Schuk, H. L. Sparks

U.S. Environmental Protection Agency
Water Engineering Research Laboratory
Cincinnati, Ohio 45268

ABSTRACT

Ozone disinfection is an environmentally attractive alternative to chlorine because of the lack of a toxic residual, its excellent virucidal properties, and its reduced potential to form hazardous constituents in the treated effluent. It is, however, energy and capital intensive relative to chlorination, and for this reason it has not been widely accepted yet in the U. S. municipal market. Any method that would reduce the operating cost of ozonation would accelerate its acceptance in that market.

In this paper we report an automated control strategy that, when implemented at treatment plants with a daily average flow greater than 8000 m^3/d, will result in a substantial savings in the electrical cost of production. The method consists of a flow proportional signal and an ozone concentration signal that combine to control the feed gas flow to and the power setting of the ozone generator according to fluctuations in liquid flow and ozone demand. The concentration signal is measured in and transmitted from the off-gas from the ozone contactor. We present an annualized cost comparison of this approach with existing strategies in use today and report a savings of \$7,000 to \$15,000 per year for a hypothetical treatment plant with a daily average flow of 23,700 m^3/day.

INTRODUCTION

Because ozone must be generated on site, the electrical energy used in its manufacture constitutes a major part of the operating cost of disinfection. Any method that would minimize the power requirement by more efficient use of the ozone applied as demand and flow fluctuate would greatly improve the cost competitiveness of ozone relative to other disinfectants. At present, the control of ozone disinfection at existing wastewater treatment facilities is usually practiced in one of two ways: either the dose or the production is held constant at all levels of flow. Dose and production are defined below:

$$D = Y_1 Q_G / Q_L \quad (1)$$

$$P = Y_1 Q_G \quad (2)$$

where D = applied dose, g/m^3
Y_1 = ozone concentration in feed gas, g/m^3
Q_G = feed gas flow rate, m^3/h
Q_L = liquid flow rate, m^3/h
P = production, g/h.

When dose is held constant, the gas flow rate is paced to liquid flow rate, while the concentration of ozone in the feed gas is held constant. Of course, as Q_G increases, the power applied to the generator must be increased in order to maintain a constant concentration. When production is held constant, the Q_G and the concentration of ozone in the feed gas are always constant. One can see quite readily that, using either of the methods above, if compliance achievement is desired a high percentage of the time, the amount of ozone applied during periods of moderate to low flow will be wasted, because dose or production must be set at the peak flow condition. What is needed is a means of automating the control of ozone disinfection as both Q_L and demand fluctuate with time. This paper will explore the use of the product of off-gas ozone concentration and contact time to control the process and discuss the economic advantages arising therefrom.

FLOW PACED OFF-GAS CONTROL

In 1984, Venosa et al. reported results from a pilot plant study indicating a highly significant log-log correlation between effluent fecal coliform levels after ozonation and the product of contactor off-gas ozone concentration and contact time. The relationship was represented by the following equation:

$$\log N = 6.35 - 3.11 \log Y_2 t \quad (r^2 = 0.85, n = 73) \qquad (3)$$

where log N = base 10 logarithm of the effluent fecal coliforms/100 mL
Y_2 = off-gas ozone concentration, mg/L
t = theoretical liquid residence time or contact time, min.

The control approach suggested by the relationship is similar in principle to compound loop control used in chlorination. As liquid flow increases, resulting in a lower contact time, a flow proportional signal is sent to the ozone generator to increase the Y_1, which causes a corresponding increase in Y_2 to offset the decline in contact time. Similarly, if the demand of the effluent suddenly increases, the Y_2 will decline due to the greater ozone transfer. The on-line ozone off-gas analyzer detects the decrease, sends a signal to the ozone generator to increase the Y_1 until the Y_2 returns to its correct setting based on the current Q_L. In this manner, a constant Y_2t is maintained regardless of the liquid flow rate or ozone demand at any given time. During periods of low flow, the dose will be low, and conversely during periods of high flow, the dose will be high. This results in a much more efficient use of the generated ozone and a corresponding reduction in operating costs.

COMPARISON OF Y_2t CONTROL WITH EXISTING METHODS

In order to compare flow-paced off-gas control with existing methods, a dose-response curve needed to be generated. Figures 1 and 2 summarize the data from the pilot plant study mentioned above. The data were generated over a four-month sampling period at two different liquid residence times: 5.2 and 9.8 minutes, corresponding to Q_L's of 130 and 70 L/min, respectively. The ozone contactor was a bubble diffuser reactor consisting of three vertical columns connected in series with wastewater effluent flowing countercurrent to the ozonized oxygen carrier gas. Figure 1 depicts effluent fecal coliforms as a function of Y_2t, while Figure 2 displays the same data as a function of applied dose. The dashed

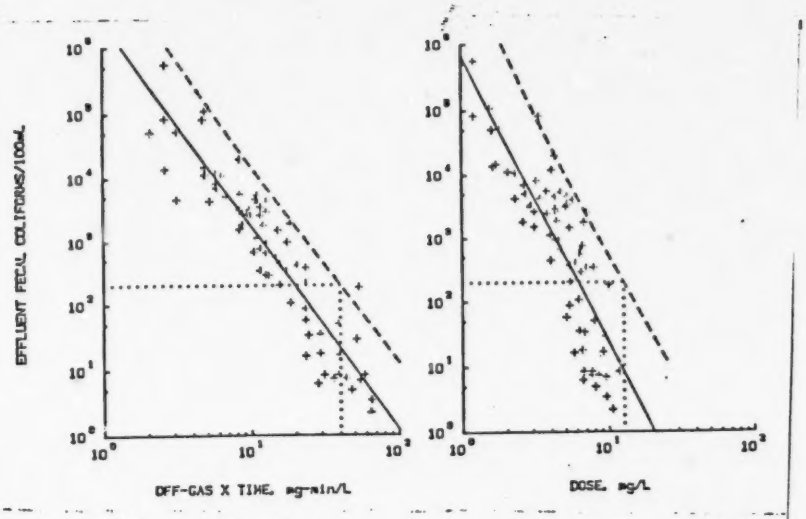

Figure 1. Effluent fecal coliforms as a function of Y_2t.

Figure 2. Effluent fecal coliforms as a function of dose.

line appearing to the right of the regression line in each case is the calculated tolerance limit representing the abscissa values needed to achieve any desired fecal coliform limit 95% of the time with 90% certainty. The methods used to compute these statistics are reported elsewhere (Venosa et al., 1984). For the sake of discussion, a compliance target of 200 fecal coliforms/ 100 mL was selected for this paper. The setpoint in each case needed to achieve a compliance reliability of 95% with 90% certainty was computed to be 40 mg-min/L in the case of Y_2t and 12.7 mg/L in the case of applied dose.

The next step was to generate data quantifying the expected changes that would occur in Q_G, D, Y_1, Y_2, and Y_1Q_G in response to changes in Q_L for each of the three control strategies (i.e., constant Y_2t, constant D, and constant Y_1Q_G). This was done using Figure 3, which shows how transfer efficiency (TE) changes with Y_1 at various constant dose levels. Transfer efficiency is the difference between the feed gas and off-gas ozone levels divided by the feed gas concentration:

$$TE = (Y_1 - Y_2)/Y_1 \qquad (4)$$

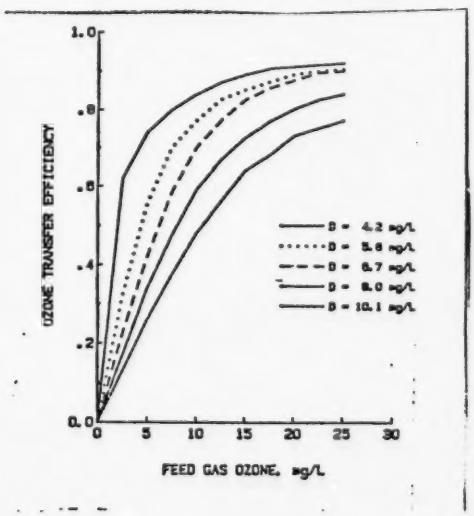

Figure 3. TE as a function of Q_G at constant dose.

Data from Figure 3 were used to produce Table 1. The following assumptions were made in this analysis:

(1) The maximum Y_1 that can efficiently be generated in air is 18 mg/L; (2) for the constant Y_2t example, a set point of 40 mg-min/L was chosen; (3) for the constant dose example, a set point of 10.1 mg/L was selected, because that's the maximum dose for which data from Figure 2 were available; and (4) for the constant production example, a set point of 600 mg/min was used (arrived at by multiplying the feed gas ozone concentration, Y_1, of 18 mg/L by an arbitrarily chosen Q_G of 33 L/min).

The pilot plant data were scaled up approximately 260-fold, from a low Q_L of 30 L/min and a high Q_L of 100 L/min to a low of 11,300 m^3/day (3 mgd) and a high of 36,300 m^3/day (10 mgd), respective-

TABLE 1 Changes in Q_G, TE, D, Y_1, Y_2, and Y_1Q_G in Response to Changes in Q_L for Each of the Three Control Strategies

Q_L, L/min	Q_G, L/min	TE	Y_1, mg/L	Y_2, mg/L	D, mg/L
		Constant Y_2t of 40 mg-min/L			
30	22	0.73	6.7	1.8	4.9
37.5	26	0.73	8.1	2.2	5.7
45	28	0.73	10.0	2.7	6.3
52.5	31	0.73	11.5	3.1	6.7
60	34	0.73	13.0	3.5	7.3
67.5	37	0.73	14.8	4.0	8.0
75	40	0.73	16.3	4.4	8.6
82.5	42	0.73	18.1	4.9	9.2
100	48	0.73	21.9	5.9	10.5
		Constant Dose of 10.1 mg/L			
30	17	0.69	18	5.6	10.1
37.5	21	0.69	18	5.6	10.1
45	25	0.69	18	5.6	10.1
52.5	30	0.69	18	5.6	10.1
60	34	0.69	18	5.6	10.1
67.5	38	0.69	18	5.6	10.1
75	42	0.69	18	5.6	10.1
82.5	47	0.69	18	5.6	10.1
100	56	0.69	18	5.6	10.1
		Constant Production of 600 mg/min			
30	33	0.27	18	13.1	19.8
37.5	33	0.44	18	10.0	15.8
45	33	0.56	18	7.9	13.1
52.5	33	0.64	18	6.4	11.2
60	33	0.70	18	5.4	9.9
67.5	33	0.76	18	4.4	8.6
75	33	0.78	18	4.0	8.0
82.5	33	0.81	18	3.4	7.2
100	33	0.87	18	2.4	5.9

ly. The carrier gas for this analysis was assumed to be air. To simulate a typical diurnal flow pattern of a municipal wastewater treatment plant, Figure 4 was created from an adaptation out of Fair, Geyer, and Okun (1968). Finally, to determine the energy efficiency (kWh/kg) of generating ozone at different air flows and production levels, data were extracted from Figure 1 of Stover (1983, p. 261), which showed for a particular ozone generator the change in production, kg/h, as a function of electrical efficiency, kWh/kg, at a number of constant gas flow rates. The latter data were needed to compare the costs and energy usage differences among the three control strategies.

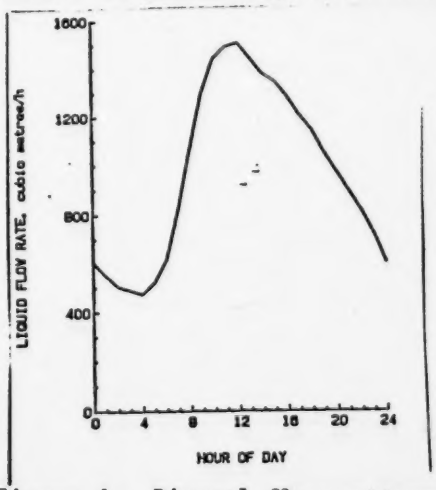

Figure 4. Diurnal flow pattern of a typical treatment plant.

RESULTS OF THE COMPARISON

Figure 5a represents the expected diurnal variation in feed gas flow rate needed to achieve the same fecal coliform compliance for each of the three control conditions. Note that at low Q_L's, less carrier gas is needed for the constant dose condition than for the other two conditions, while at higher Q_L's, less feed gas flow is needed for the constant Y_2t condition. Figure 5b shows the change in ozone production during a typical treatment day for the three conditions. Production is lower for the constant Y_2t condition than the constant dose condition at all times of the day except at peak flow. In the case of constant production, the kg/h produced is substantially higher than the other two cases at low flows, but lower at high flows. Thus, in the case of the constant production strategy, almost 50% of the time too much ozone is produced, while the other 50% of the time too little is produced, resulting in a lower compliance frequency overall.

Figure 5c is a plot of the energy efficiency against hour of the day for each of the three control strategies. Clearly, the condition that uses the least amount of electrical power per unit of ozone produced is the constant Y_2t case, except at peak flow conditions between the 9th and 16th hour of the day. Finally, as seen from Figure 5d, actual power usage in terms of kWh/h is significantly less in the case of constant Y_2t than in the case of constant D. The constant production strategy uses less energy than constant Y_2t approximately 10 hours of the day.

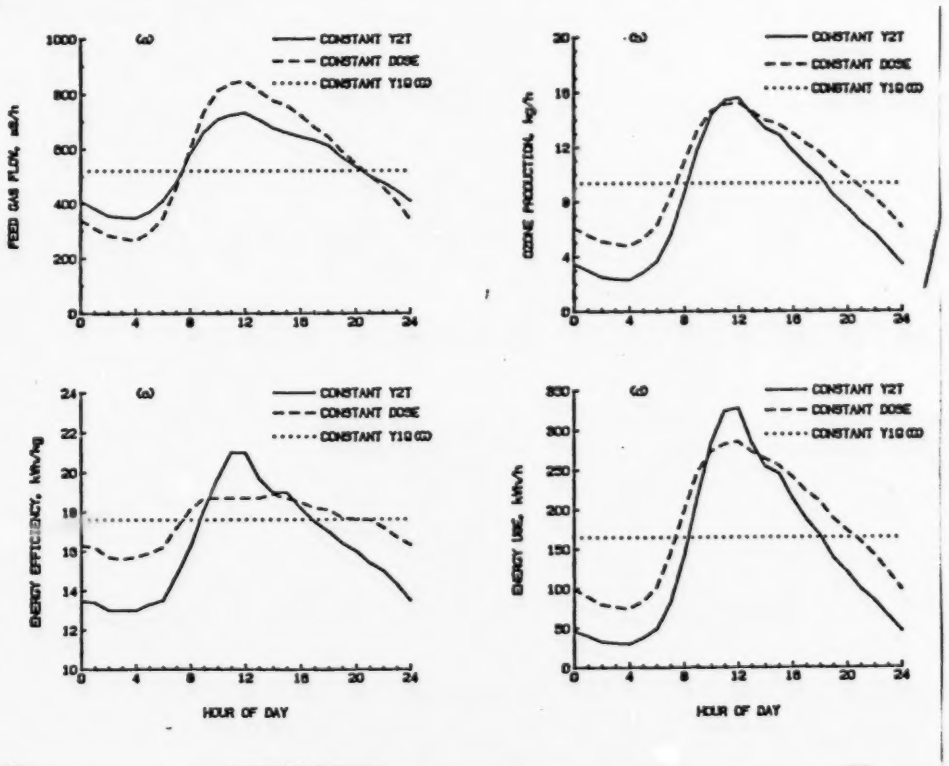

Figure 5. Diurnal pattern of (a) gas flow, (b) production, (c) energy efficiency, and (d) energy usage for each control strategy.

EXPLANATION OF FINDINGS

Figures 6a-c were developed to explain the energy savings that obtains when ozone disinfection is controlled by flow-paced off-gas analysis. From Figure 6a, it is

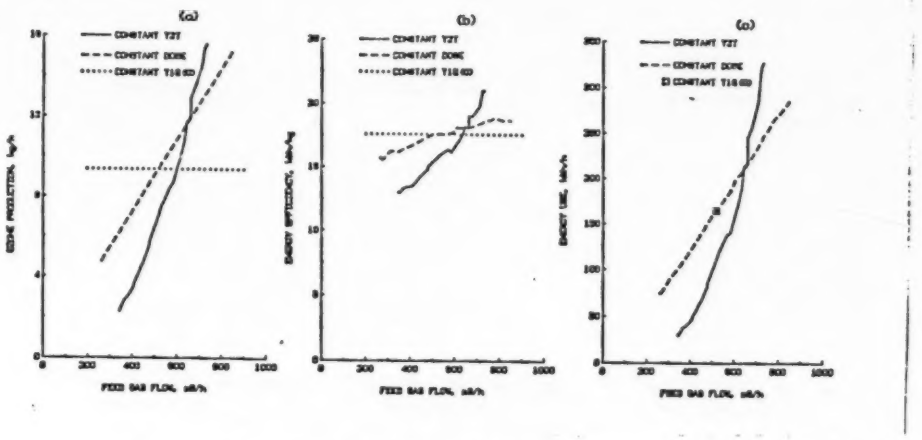

Figure 6. Effect of gas flow on (a) production, (b) energy efficiency, and (c) energy use for each control strategy.

evident that at a constant ozone production rate, more feed gas is used in the case of Y_2t control than in constant dose control, up to approximately 11 to 12 kg/h. Above that point, constant dose control uses more feed gas per unit ozone production. What this means is that at $Q_G < 650$ m^3/h a higher concentration of ozone is required in the case of constant dose control to provide for the same level of production as constant Y_2t control. This results in a higher unit energy requirement at a given Q_G in the former (Figure 6b), and the actual power usage (kWh/h) is greater (Figure 6c) up to the crossover point at approximately 650 m^3/h. When energy usage is evaluated as a function of ozone production rate (Figure 7), the three control strategies are equivalent, as expected. Since electrical energy usage is the same per unit production rate regardless of the control strategy used, it follows that flow-paced off-gas control should be the method of choice, since the least amount of ozone production is required throughout a treatment day to achieve compliance with the disinfection standard.

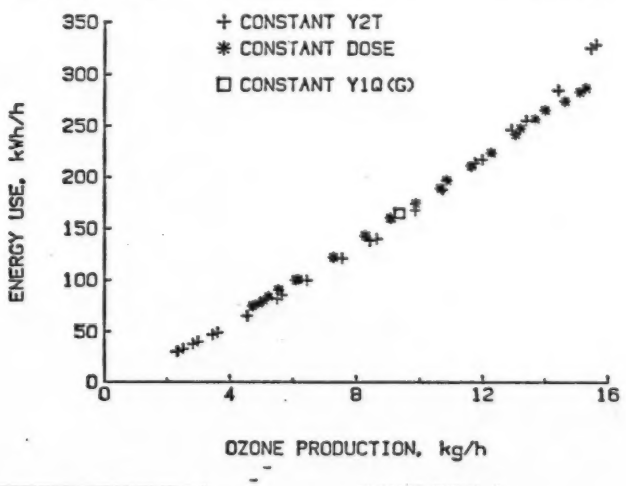

Figure 7. Change in energy usage as a function of ozone production.

ECONOMIC COMPARISON

In order to compare properly the annual costs of the three process control strategies above, it is first necessary to consider the instrumentation needed for automation in each case. The most sophisticated control approach, constant Y_2t, requires two continuous ultraviolet photometric ozone analyzers to monitor

both Y_1 and Y_2, and a microprocessor to manage the generator set point and all the input and output flow and concentration signals that impact that set point. Such a microprocessor would involve an initial capital investment of approximately $10,000. A typical ozone analyzer manufactured by Dasibi Environmental, Inc., retails for approximately $4,300. Thus, the total annual instrumentation cost for constant Y_2t control, $18,600 amortized at 10% per year for 10 years, amounts to $3,030.

In the case of maintaining a constant dose, which requires measuring Y_1 and Q_L, one ozone analyzer and a ratio controller with square root extractor for flow proportional control are needed. Cost of the latter is estimated at $3,000. Thus, amortizing $7,300 for 10 years at 10% yields an annual instrumentation cost of $1,190.

To maintain a constant ozone production, it is not necessary to measure Y_1 or Y_2 at all, since the generator setting is constant. So, too, will be the gas flow setting. The only instrument necessary in this case is a recording gas flow meter to make certain that the Q_G is maintained constant at all times. This would demand a small initial investment of approximately $1,000, which amortizes to $160/year.

It should be emphasized that in all these cases certain items such as gas flow meters, liquid flow monitoring equipment, etc., will be needed in addition to the materials mentioned above. The costs of these items, however, are the same for all the control approaches and so are not included in this analysis.

To determine the daily energy usage in each case, the areas under the curves in Figure 5d were integrated, resulting in the following kWh/day electrical costs: 3504 for constant Y_2t, 4291 for constant dose, and 3950 for constant production. The average daily wastewater flow from integrating the area under the curve in Figure 4 is 23,745 m^3/d (6.3 mgd). Unit electrical cost was assumed to be $0.06/kWh. Thus, the annual electrical cost of producing ozone for this hypothetical treatment plant is $76,740 using constant Y_2t control, $86,510 using constant production control, and $93,970 using constant dose control. Adding to these figures the annualized instrumentation costs results in a total yearly outlay of $79,770 for constant Y_2t, $86,670 for constant Y_1Q_G, and $95,160 for constant dose. Figure 8 summarizes this in the form of a bar chart. Clearly, the annual savings in operating costs accruing to the treatment plant incorporating flow-paced off-gas control is substantial, and the reliability of the process is not compromised in the least.

CONCLUSION

Control of ozone disinfection by an automated compound loop mechanism has been presented and economically analyzed for the first time. The control loop consists of a flow-proportional signal and an off-gas signal from the ozone contactor, both of which combine to maintain a constant Y_2t set point. The set point is determined empirically. Data were presented supporting the claim that such a control mechanism could result in a significant reduction in annual operating costs of an ozone facility. The cost savings only accrue at treatment plants with daily average flows greater than 8000 m^3/d (2.1 mgd). It should also be pointed out that, in the case of the constant production strategy, the set point selected for this paper would result in a coliform compliance frequency somewhat lower than the 95% assumed for the Y_2t case.

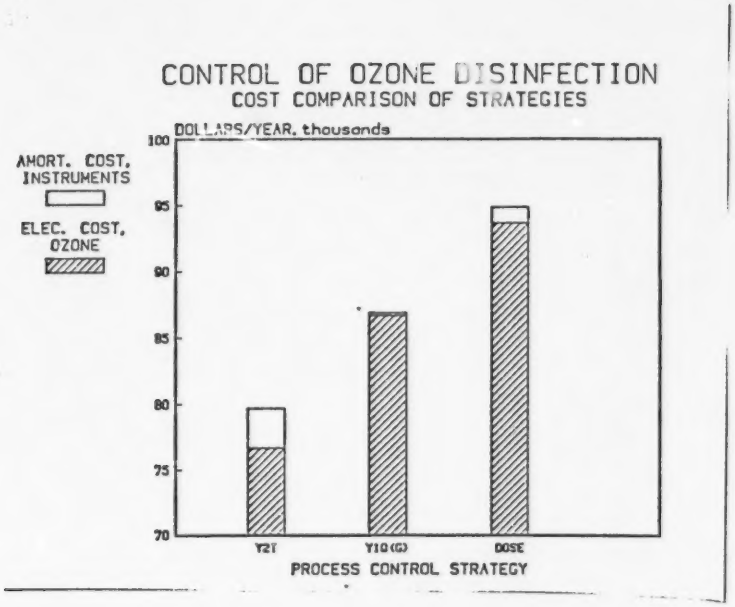

Figure 8. Total annual operating cost of ozone disinfection for each control strategy for a hypothetical 23,700 m^3/d treatment plant.

REFERENCES

Fair, G. M., Geyer, J. C., and Okun, D. A. (1968). Water and Wastewater Engineering. Vol. 2. Water Purification and Wastewater Treatment and Disposal. John Wiley & Sons, Inc., New York, p. 20-18.

Stover, E. L. (1983). Optimizing operational control of ozone disinfection. In: Municipal Wastewater Disinfection Proc. Second National Symp., A. D. Venosa and E. W. Akin (Ed)., EPA-600/9-83-009, pp. 260-277.

Venosa, A. D., Rossman, L. A., and Sparks, H. S. (1984). Reliability of off-gas measurement to control ozone disinfection. Abstracts of Technical Papers, 57th Annual Conference, Water Pollut. Control Fed. (Submitted to J. Water Pollut. Control Fed.).